Biodegradation of phenol and its derivatives in packed and moving bed bioreactors using *Bacillus* sp. isolated from petroleum site

Thesis submitted in partial fulfillment for the

Award of degree

DOCTOR OF PHILOSOPHY

By

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Under the supervision of

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Dedication

I dedicated this Ph.D. thesis to the 139 crore Indians who paid the cost of this study; I am greatly indebted to them

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I, **Ganesh Swain**, a research scholar under the supervision of **Prof. B.N. Rai** and co-supervision of **Dr. Ravi P. Jaiswal**, Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi, India give undertaking that the thesis entitled **"Biodegradation of phenol and its derivatives in packed and moving bed bioreactors using *Bacillus* sp. isolated from petroleum site"** submitted by me for the degree of Doctor of Philosophy is a record of first-hand research work done by me during the period of study.

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I, **Ganesh Swain**, certify that the work embodied in this Ph.D. thesis is my bonafide work carried out by me under the supervision of **Prof. B.N. Rai** and co-supervision of **Dr. Ravi P. Jaiswal** from **July 2017 to December 2021** at the Department of Chemical Engineering & Technology, Indian Institute of Technology (BHU), Varanasi, India. The matter embodied in this Ph.D. thesis has not been submitted to award any other degree/diploma. I declare that I have faithfully acknowledged and given credit to the research workers whenever their works have been cited in the text and the body of the thesis. I further declared that I have not willfully lifted some other work, paragraph, text, data, results, etc., reported dissertations, thesis, etc., or available at websites and included them in this Ph.D. thesis and cited as my work.

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Abbreviations

Abbreviation	Nomenclature
4-CP	4-chlorophenol
2,4-DCP	2,4-Dichlorophenol
P-NP	Para-Nitrophenol
DO	Dissolved oxygen (mg/L)
PBBR	Packed bed bioreactor
LDPE	Low-density polyethylene
PUF	Poly urethane foam
PP	polypropylene
HRT	Hydraulic retention time (h)
RE	Removal efficiency (%)
EC	Elimination capacity (mg/L.d)
ILR	Inlet loading rate (mg/L.d)
MSM	Minimal salt medium
MBBR	Moving bed biofilm reactor
RSM	Response surface methodology
COD	Chemical oxygen demand (mg/L)
CCD	Central composite design
μ_{max}	Maximum specific growth rate (day^{-1})
K_s	Half-saturation constant (mg/L)
K_i	Substrate inhibition constant

S_0, F_0	Initial substrate concentration (mg/L)
S, F	Final substrate concentration (mg/L)
U_{max}	Maximum substrate utilization rate (mg/L. d)
X	Biomass concentration (mg/L)
V	Volume of the bioreactor (L)
Q	Feed flow rate (mL/h)

Preface

Industrialization has improved the living style and economic prospects of the people as well as the country. In the meantime, the toxic pollutants (mainly phenol, phenolic derivatives, dyes, polycyclic aromatic hydrocarbons, etc.) are discharged to the ecosystem by various industries like petroleum, pharmaceutical, paints, and pesticides, and cause environmental issues. The carcinogenic, mutagenic, and teratogenic properties of the pollutants make researchers to explore cost-effective and eco-friendly technology for the degradation of such pollutants. In this direction, the biodegradation process is preferred as an effective tool for the mineralization of xenobiotic compounds.

The adopted microorganisms which have a history of exposure to the contaminated site exhibit higher biodegradation rates than other microorganisms. Hence, the acclimatization and isolation of the potent microbial species can enhance the biodegradation rate. The real-time applications of various microorganisms and packing support have been widely studied for wastewater treatment. However, the continuous performance evaluation of attached-growth bioreactors, such as packed bed bioreactor (PBBR) and moving bed bioreactor (MBBR), are relatively less researched for such applications. The objective of this study is to evaluate the efficacy of the potential bacterial species isolated from a petroleum contaminated site for the biodegradation of phenol and its derivatives in the PBBR and MBBR. In addition, this study employed the low-density polyethylene and polyurethane foam, a packaging waste, in bioreactors for the purpose of bacterial immobilization. A comparative analysis has also been carried out to investigate the performance of PBBR and MBBR operated at identical conditions.

The present thesis is categorized into **5 chapters**. **Chapter 1** embeds the introduction (sources and toxic effect) of phenol and its derivatives, treatment methods, and various factors affecting the biodegradation process. **Chapter 2** contains a detailed analysis of the literature review, research gaps, and the objective of the thesis work. **Chapter 3** includes the materials and methods of the experimental work. The results and discussions (phenol biodegradation, 4-chlorophenol biodegradation, and comparative study between PBBR and MBBR) are briefly explained in **Chapter 4.** The conclusions of the thesis work and the scope for future work have been mentioned in **Chapter 5.**